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Trends in Technological Development and Research on Waste Material Treatment Aimed at Constructing a Recycling-Oriented Society

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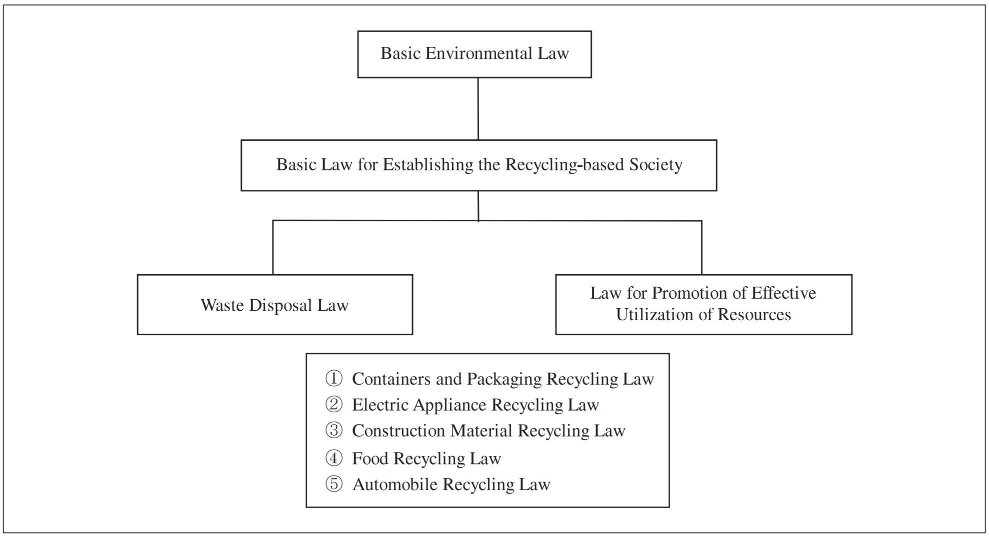
6.1 Introduction

As the treatment of waste materials discharged in large amounts from homes, factories and so on becomes a social problem of increasing magnitude, the economic activities of mass production and mass consumption that have supported Japan's economic growth are beginning to undergo a major turnaround in the direction of recycling and utilizing waste material as useful resources, with the aim of conserving resources and energy. The government is gradually implementing laws that oblige the recycling of container packaging, four home appliance items, construction waste materials, food products and automobiles, and also takes up "research for constructing a recycling-based society" in its Second Science and Technology Basic Plan. In response to this, the Council for Science and Technology Policy, Cabinet Office, has incorporated "research on zero waste-type and resource recycling-type technologies" as one of the key points to emphasize in the environmental field of Promotional Strategies of Prioritized Areas, and in the social foundation field also, refers to countermeasures for harmful and dangerous substances that are generated through the progress of science and technology. In addition, the Council on Economic and Fiscal Policy's expert panel on recycling-oriented economy and society is also advancing investigations into measures for utilizing waste as resources and energy.

As a powerful measure to reduce the burden on the environment, industry, academia and government are working on a variety of research and technological development in regard to the "Realization of Zero Emissions," wherein waste materials are ultimately eliminated, with the amount of physical distribution in making products from virgin raw materials in factories (artery distribution) and the amount of physical distribution in recycling unnecessary items from factories and homes and making them into raw materials for factories (vein distribution) taken as the same level. In industrial circles in particular, some see that with the implementation of recycling-related laws, a promising market will be created as environmental business, and technology for environmental measures is being developed successively by a number of companies. Nevertheless, it still can not be said that the technology is established that supports the industries (vein industries) that support vein distribution. For this reason, the recycling of general waste material (approx. 51 million tons/yr.) and industrial waste (approx. 400 million tons/yr.) by vein industries is limited to only a portion, and given that the new construction of final treatment stations for industrial waste material has fallen sharply since 1999[1], the speedy establishment of recycling technology is sought.

This report analyses the current state of research and technological development of waste material treatment and efforts towards commercialization, with the classification of waste material in recycling-related laws as a basis. Furthermore, it also refers to themes in research and technological development that should be tackled in constructing a diversified recycling-oriented society.

Figure 1: Legal system for promoting formation of recycling-oriented society



Source: Authors' compilation based on Reference [2]

Table 1: Regulations based on characteristics of individual items

Name of law	Date of introduction and promulgation	Aims and objectives
Containers and Packaging Recycling Law	Introduced April 2000	- Collection of container packaging by cities, towns and villages - Recycling of container packaging by manufacturers and user companies
Electric Appliance Recycling Law	Introduced April 2001	- Taking back of discarded home appliances from consumers by retailers - Recommodification by manufacturers, etc.
Construction Material Recycling Law	Introduced May 2002	- Separation anddismantling of structures and recycling of building waste material by construction contractors
Food Recycling Law	Introduced May 2001	- Rrecycling of food product waste materials by food product manufacturers, processors and vendors
Automobile Recycling Law	Promulgated July 2002	- Taking back and recycling of CFCs, airbags and shredder dusts by automobile manufacturers

Source: Authors' compilation based on Reference [2]

6.2 Legal framework promoting the formation of a recycling-oriented society

Within the legal system aimed at the formation of a recycling-oriented society (Figure 1), the fundamental framework of ensuring material circulation and controlling consumption of natural resources is prescribed in the "Basic Law for Establishing the Recycling-oriented Society." In order to establish a general mechanism, the "Waste Disposal Law" aimed at appropriate treatment of waste material, and the "Law for Promotion of Effective Utilization of Resources" aimed at recycling promotion, have been enacted.

Regulations that correspond to the characteristics of individual items are the so-called five recycling-related laws. Targeted in the five related laws are container packaging, four home appliance items, building materials, food products and automobiles, with objectives and aims like those indicated in Table1.

6.3 Efforts to develop and commercialize recycling technology

Since waste materials exist in many different forms, development of recycling technology is manifold, and there is a large number of items produced by the recycling business. In regard to recycling technology of waste materials that are targeted in the recycling-related laws, this section

Table 2: Development status of representative material and chemical recycling methods

Type of waste material	Recycling technology	End-use of recycled and generated products
Polyesters (PET bottles, etc.)	- Separation and high purity flaking	- Polyester clothing, office and home supplies, etc. for open market
Plastics	- Production of PET raw materials - Oilification - Turning into ingredients for cement - Regeneration - Extraction of chemical substances such as hydrochloric acid and acetic acid	- Heat source for own factory and others - Cement manufacture - Chemical and pharmaceutical manufacture
Electric appliances, OA equipment	- Separation and dismantling - CFC recovery	- Ingredients of metal and glass products
Food residues, Wastes produced from food manufacturing	- Feed production - Turning into biodegradable plastics - Turning into valuable gases by fermentation	- Formula feed production - Soil improvement
Automobiles (shredder dusts)	- Separation of metals and nonmetals - Utilization of organic materials (urethanes, etc.) - Oilification (waste plastics, etc.	- Ingredients of metal and glass products - Roadbed material, etc.

analyses (1) R&D and commercialization of recycling technology; (2) a comparison of material recycling technology and conventional manufacturing technology; (3) the role of industry, academia and government in recycling commercialization; and (4) collaboration of recycling businesses.

6.3.1 R&D and commercialization of recycling technology

The direction of recycling technology development encompasses material recycling, which does not change the compositional state of material; chemical recycling, which changes chemical constituents; and thermal recycling, which burns material and uses it as heat and also electrical power, but since recycling technology is extremely diverse, it is difficult to simply classify it into these types.

(1) Material recycling and chemical recycling

With the objective of regional promotion through promotion of environmental industries, the Ministry of Economy, Trade and Industry is cooperating with the Ministry of the Environment in promoting Eco-Town Projects. Table 2 shows the result of classifying recycling technologies including those developed in these Eco-Town Projects, and the end-use of the recycled products they produce, with a focus on material recycling and chemical recycling.

(2) Thermal recycling

Products generated by recycling technologies are used as resources by vein industries, and also serve as an energy source. Electrical power is the primary form of energy source, and there are also valuable gases such as steam and hydrogen. Thermal recycling, whose final objective is electric power generation, includes primarily those technologies shown in Table 3.

In the case of conventional incinerator systems, stoker furnaces are becoming widespread, where refuse is sent and heated in the furnace by a box-shaped metal block called a “stoker,” and in the Tomakomai East development region, a commercial power station burning only waste plastics went into operation in November 2002, while in Omuta City, a power station burning only RDF (See Footnote 1) by the third-sector system commenced operations in December 2002.

Among the electricity generation systems of Table 3, the technology attracting the most attention of late is gas conversion type electric power generation technology [4], [5]. With gas conversion type electric power generation technology, various waste materials are pyrolyzed under high temperatures of about 600 degrees

Footnote 1:

Abbreviation for Refuse-Derived Fuel:combustible refuse that has been crushed, dried, sorted and compression-molded into solid fuel.

Table 3: Development status of representative thermal recycling technologies

System of electric Power generation	Amount of waste material treatment (tons/day)	Method of electric power generation	Main developer	Level of technological development
Conventional incinerator system	> approx. 600	Generates high temperature, high-pressure steam by incineration, with plastics and food residues as a fuel; electric power generated by steam turbines	Large companies	Practical use
Gasification-melting system	Approx. 200-600	Waste material fuel is "casseroled" to generate flammable gas, and the high temperature generated during gas combustion is used to drive steam turbines	Large companies, some universities	Practical use
Gas conversion system	<approx. 200	Waste material fuel is "casseroled" to generate flammable gas; after gas quality is improved, it is used for fuel in internal-combustion engines	NEDO (large companies commissioned), some universities	Under development

Celsius or more, and then after reforming of soot and tar components into hydrogen gas, the fuel gas is separated from molten ash called slag. The fuel gas is used for electric power generation in gas engines and so on, while the slag is used for road paving material. With gas conversion technology, it is possible to utilize a wide range of waste material as fuel, whether it be domestic waste material or industrial wastes, and by effectively utilizing slag as well, there are high expectations in it as a final stage treatment technology. Since fiscal 2001, NEDO (New Energy and Industrial Technology Development Organization), large companies commissioned by it and others have been researching gas conversion type power generation technology that can be used in comparatively small waste material treatment facilities of 200 tons/day or less. Also, Tokyo Institute of Technology has developed a small-sized waste material gas conversion power generation technology that is economically and technically viable even with waste material amounts as little as 500 kg/day, which a small regional community of around eight thousand people is proceeding to introduce.

6.3.2 Comparison of material recycling technology and conventional manufacturing technology

When compared to manufacturing technologies in conventional manufacturing industries, material recycling technology like that shown in Table 2 that produces recycled goods has the same meaning of “making things,” but there is a significant difference in raw materials and product standards. Table 4 is a comparison of both technologies.

One major reason for differences like those shown in Table 4 is “the nature of the raw material.” In conventional manufacturing

Table 4: Comparison of features of material recycling technology and conventional manufacturing technology

Item for comparison		Material recycling technology	Conventional manufacturing technology
Raw material	Quality	Highly dependent on quality and quantity of separation work	Generally, dependent on technology of raw material refining plants, high purity
	Price	Highly dependent on cost of separation, collection and transportation	Dependent on reserves and production costs of refining plant
	Supply amount	Restricted by total amount of waste material	Restricted by mining technology and scales of raw material production plant
	Guarantee of necessary amount	No guarantee to operators	Easy (dependent on circumstances at time of importation)
Standard of recycling or manufactured goods		None	Many such as JIS or JAS
Principal factors determining predominance of technology		Cheapest treatment technology predominant	Technology with low manufacturing cost and high quality is predominant

Source: Authors’ compilation based on Reference [2] technology, a large-scale raw material supply system is in place, so methods that enable intensive production at low cost and high quality are widely used. In contrast, since waste material is the raw material in the case of material recycling technology, technology that keeps down the cost incurred in separation, collection and transportation and can produce goods at the lowest cost, is strongly competitive. Even if material recycling technology was able to produce recycled goods of the same quality as goods made with conventional manufacturing technology, unless the technology can efficiently turn out recycled goods from limited waste materials, the relatively high production costs are an obstacle and diffusion in the market will be difficult.

6.3.3 Role of industry, academia and government in commercialization of recycling

With the recycling technology borne of research and technological development as a foundation, industry, academia and government are taking part from their respective standpoints in the commercialization of recycling as Eco-Town Projects and so forth. Even though particulars differ in the respective Eco-Town Projects, industry, research institutions centering on universities, administrative institutions such as the State and local municipalities, etc., are performing roles like those shown in Table 5. In addition to industry, academia and government, the role that the inhabitants (citizens) should play in the commercialization of recycling is also significant. This is based on the reasons that the inhabitants are producers of domestic waste material and are required to assume a role in the separation of waste material, and without the agreement of citizens who live in the area surrounding a waste material treatment facility, the installation of such a facility is difficult.

6.3.4 Collaboration of recycling businesses

Among the production processes of recycling businesses, for example there is a flow where one recycling agent will make polyester flakes from PET bottles, and a company uses that as raw material to make polyester fiber, from which it makes clothing. And on the Sapporo City Recycling Estate, there are also plans for an oilification company that manufactures light oil substitute fuel oil from waste plastic products such as polypropylene, to supply a nearby food product waste material treatment company with fuel oil for use as heater fuel in its feed-making process. Theses cases demonstrate how two recycling companies are beginning to have a collaborative relationship, by the product of one recycling company becoming the raw material of another recycling company. This connection is the same as the flow of raw material processing and manufacture in ordinary manufacturing businesses, and means that vein industries are constructing the same machinery as artery industries. Looking closely at the connection between recycling businesses and ordinary manufacturing businesses in this kind of situation, we can describe a simplified flow chart of resources like that shown in Figure 2.

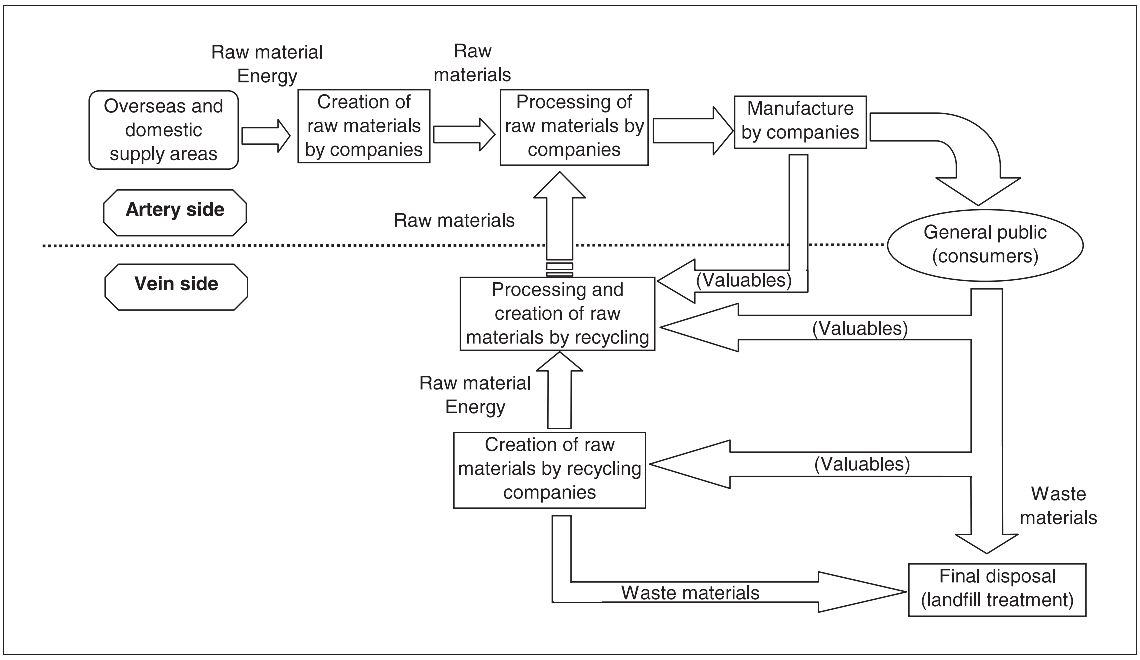
6.4 Recycling research and technological development aimed at zero emissions

Zero Emissions is a framework that was advocated by the United Nations University in

Table 5: Role of industry, academia, government and citizenry taking Eco-Town Projects as an example

Category	Role
Industry (including company federations)	- Development of basic technology - Lead in commercialization
Research institutions such as universities	- Support of technological development
Administrative body	- Attracting recycling businesses, land leasing - Facilitation of administrative procedures in commercialization - Monitoring of environmental impact
Inhabitants (citizenry)	- Sharing responsibility of separation work - Acceptance and agreement to waste material treatment facilities

Figure 2: Simplified flow of resources in artery industries and vein industries



1994 based on the "Rio Declaration on Environment and Development" and "Agenda 21" action plan, fundamental ideas for global environmental preservation that were adopted at the 1992 Earth Summit. In the case of the United Nations University Zero Emissions research concept, it is expressed that, "Zero Emissions envisages all industrial inputs being used in the final products or converted into value-added inputs for other industries or processes. In this way, industries will reorganize into "clusters" such that each industry's wastes/byproducts are fully matched with others' input requirements, and the integrated whole produces no waste of any kind." (See Footnote 2)

Since the United Nations University did not strictly define the limits within which the "Zero Emissions" concept could be applied, a variety of interpretations arose and as a result, a variety of strategies stipulating Zero Emissions arose in companies and regions. We can classify activities aimed at Zero Emissions into three types. The first type comprises strategies in industrial facilities such as factories and places of business. The second comprises strategies by multiple companies in an industrial estate, etc., and the work of Kofu City's Kyodo Kumiai Kokubo Industrial Estate Association in which twenty-seven companies participate is well known as one successful example of this type. The third consists of strategies in areas such as cities, towns and villages and communities, and there are examples in the Kitakyushu Eco-Town Project and Sapporo City Recycling Estate.

The first and second activities are realized as Zero Emissions-targeted activities by companies on the artery side in Figure 2. With the third model, autonomous bodies, etc., promote the realization of Zero Emissions, with the cluster of recycling companies on the vein side assuming a major role in those activities. What the clusters of companies on both the artery side and vein side aim for is ultimately realizing zero waste and resource circulation by innovating manufacturing and recycling technology systems, and also

Footnote 2:

Pamphlet of the United Nations University Zero Emissions Research Concept describes as follows:

"Zero Emissions envisages all industrial inputs being used in the final products or converted into value-added inputs for other industries or processes. In this way, industries will reorganize into "clusters" such that each industry's wastes / by-products are fully matched with others' input requirements, and the integrated whole produces no waste of any kind."

reducing the amount of material finally disposed of as waste material in that process.

At the same time, there are also factors standing in the way of achieving Zero Emissions. In the case of waste material of undetermined composition that has been illegally disposed in large amounts, recycling research and technological development has made scarcely any progress. Furthermore, toxic and hazardous substances such as dioxins that occur in artery industries are temporarily held in check in resource circulation, and urgent technological development is called for to render these harmless.

6.5 Promotion of recycling research and technological development

In regard to research and technological development aimed at Zero Emissions, there are many points at issue that need to be discussed multilaterally. Particulars that should be discussed are for example,

- What methods are there to adapt the principles of research and technological development in universities, etc. to the needs from autonomous bodies;
- What is necessary in order to tie in the results of research and technological development to commercialization;
- How should vein industries be positioned as an element in social systems;
- What are the roles to be borne by industry, research institutions, government and local inhabitants.

In this section, we will focus our discussion on these points at issue.

(1) Role played by universities

Many university researchers are pursuing a variety of research with a view to developing technology that can be put to practical use, but there are numerous cases where the level of research is still at the technological development stage. At the same time, many municipalities, in order to treat domestic waste material are introducing recycling technology that companies have applied, and are also interested in introducing recycling technology that is currently being developed by universities, such as technology that extracts valuable gases from food product waste for use in power generation, and technology that turns food product waste into animal feed. Of the recycling technologies that municipalities have thus far introduced, it would be difficult to say that university results form the foundation. In university research and technological development hereafter, there is a need to advance research while taking into account the needs of municipalities. As an example of that policy, local universities could be commissioned to research solutions to the waste material problems that individual municipalities are confronted with, and engage in research and technological development under close cooperation.

(2) Efforts towards commercialization

In order to grow and diffuse as a business the waste material treatment technology such as recycling technology that is developed in universities, there are two issues that need to be resolved. The first is that there is a large difference in the scale of research at universities, etc., and the scale of commercialization, and fresh technical issues arise due to this scale difference. The second is the need for development of efficient technology such that the aggregate of waste material treatment commission costs and the sales income of recycled products exceeds the cost of recycling waste materials treatment.

As an approach to the first problem, for example in regard to recycling technology, universities that developed the technology and companies or municipalities with an interest in commercialization could join forces to run trials on a field test scale. This would confirm the possibility of the technology's diffusion and of devising measures to deal with fresh technical issues that arise at the commercialization scale.

As an approach to the second problem, large-sized waste material-burning power generation equipment that has been introduced mainly in large urban refuse incineration facilities is cited as a reference case. Advanced technology was developed for this burning-type power generation equipment, but factors have hindered its diffusion, such as business profitability declining due to excessive treatment capacity, and restrictions on municipalities with needs. On the basis of this, the development of small-scale, commercially viable burning-type power generation equipment (high-efficiency small-scale refuse (–burning) power generation) is being carried out by NEDO, numerous companies and universities, etc. Based on this kind of case, promotion of equipment design and technological development is needed, with the prerequisite condition that scale is commensurate with the waste material collection plans in a region that an municipality envisages.

(3) Positioning in the social system

It is also important to make vein industries function effectively as a member of the social system. At present, a one-pattern business form is mainstream, wherein products recycled from waste materials are supplied directly to consumers and processors in artery industries. At the same time, business types are also emerging that supply recycled products as raw materials or energy sources of other vein industries, and there are signs that companies on the vein side are networking. In order to effectively promote the creation of future vein industries, autonomous bodies are supporting research and technological development in business site leasing, bulletins of administrative procedures, and so forth. In addition to these, measures to support recycling companies are necessary, such as the state or municipalities establishing a system like "Green Certificates," so that raw materials recycled by vein industries are actively used.

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